Why Carbon will remain essential for the transition to Carbon Neutral Steelmaking

Carl De Maré

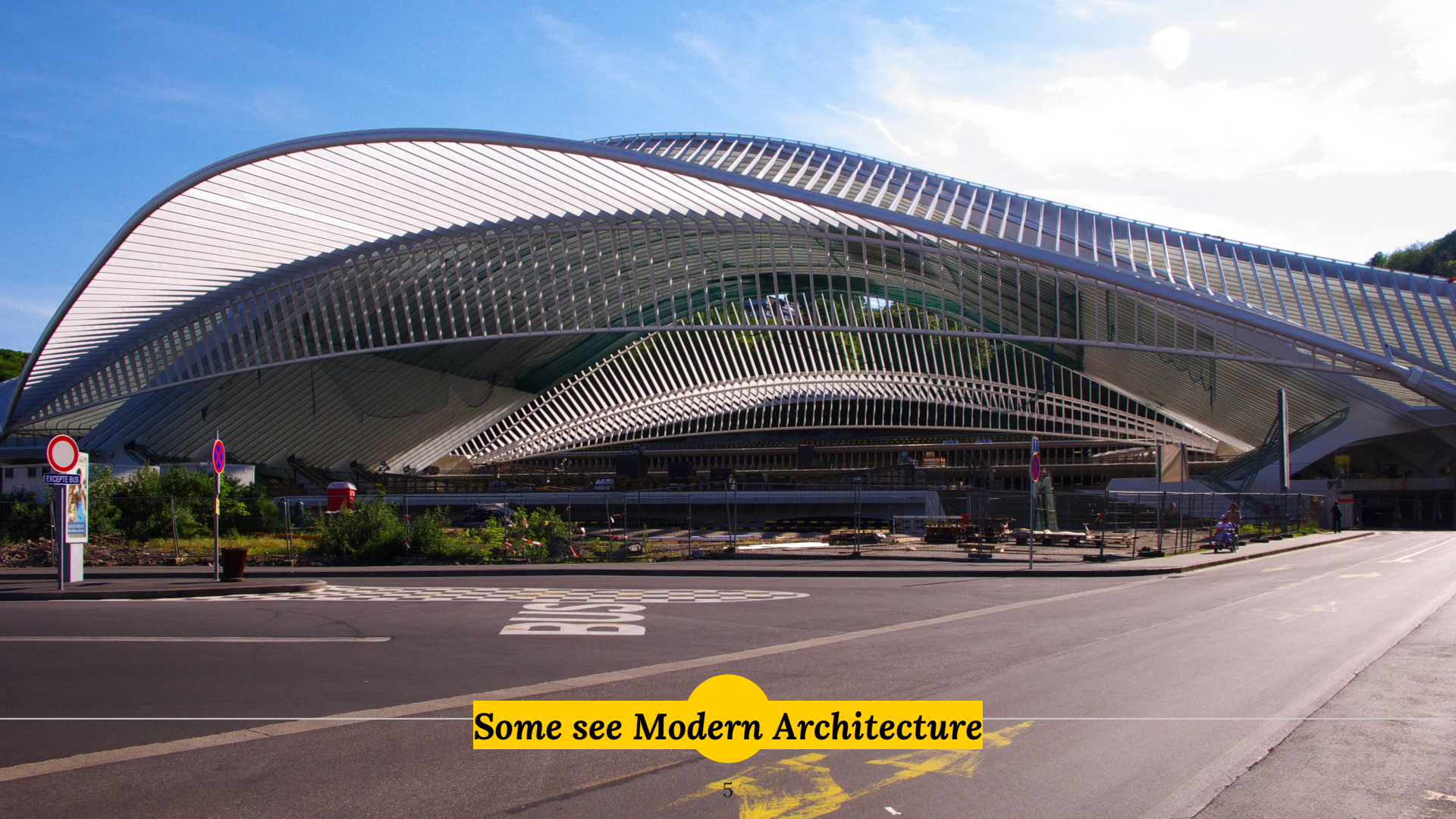
SEII, Brussels 27 October 2022

Steel is needed everywhere

"Rodrigo Duterte", Former-President of Philippines, 2016 -2022


Some see Renewable Energy

Some see the Heroes of their Youth



Some see Modern Architecture

Steel is needed everywhere
Figure per Capita in Developed Economies

Steel in use

10 ton / 

Steel consumption per day

1 kg per day / 

3 cycles of 75 years

Start Bessemer-Siemens-Martin convertor

Hot Air blowing On cast Iron

Start LD-BOF convertor

Oxygen Blowing

Start Smart Carbon Steelmaking

Carbon Neutrality & Circularity

? Start 4th ERA of mainly scap based steel

Until 1872: Steel is costly and exceptional

Steel is exceptional, only for tools and swords, costly and labor intensive

All large constructions are made out of cast iron.

Start of Steelmaking
Bessemer/Siemens-Martin

1872 | 1947 | 2022 | 2097

1872 - 1947

1882 – Edisons First Central Powerplant in London for Street lightning on DC current
1885 – Daimler and Benz build First automobile on liquid petrol engines
1886 – Rover Safety Bicycle
1887 – Hertz generates for the first time electromagnetic waves
1889 – First high voltage AC power station at 85 Hz
1889 – First electrical power transmission line at 4 kV

Start of Steelmaking
Bessemer/Siemens-Martin

1872 - 1947

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Start of Steelmaking
Bessemer/Siemens-Martin

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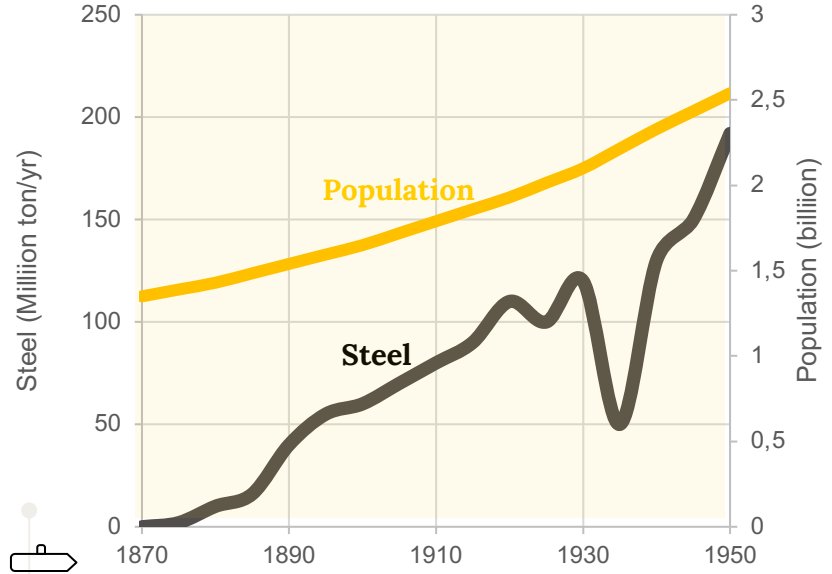
1872 – 1947 : First Cycle of 75 years

1,35 B

0 Mt Steel



2,5 B (2x)

170 Mt Steel (x 1000)

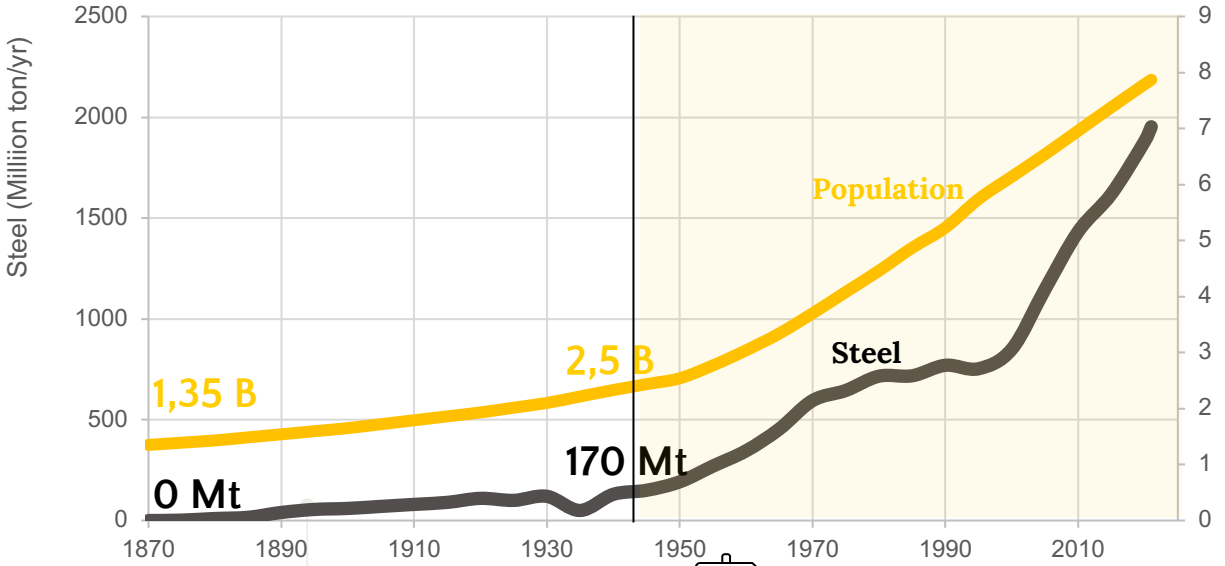
1872 | 1947 | 2022 | 2097

1947 : Start new area of Oxygen Steelmaking with the LD-BOF invention (Switzerland / Austria)

- Scale up from 30 to 300 ton/heat (x 10)
- Labor productivity from 3 to 0,003 ton/FTE (x1000)
- Energy consumption from 35 GJ/t to 18,7 GJ/t (/ 2)
- Over the period 1920 – 2020, steel price has remains constant, beating the inflation

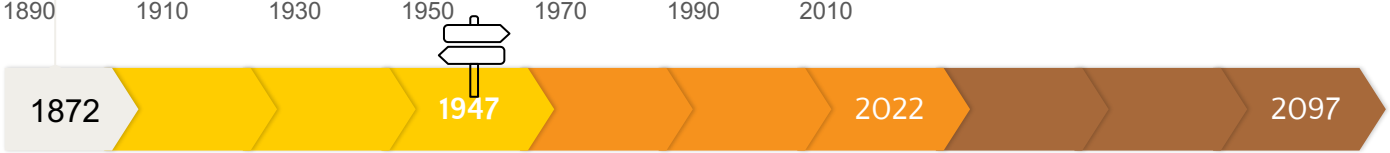
Invention of LD BOF technology in 1948

1947 – 2022 : 2nd Cycle of 75 years



8,0 B (x 3,2)

1953 Mt Steel (x11,5)



2022 - 2097 : Steel needs will further increase

2022

5 ton/p
x
8 b people
=
40 billion ton

2097

10 t/p
x
10b people
=
100 billion ton

Steel in Use World Averages per capita

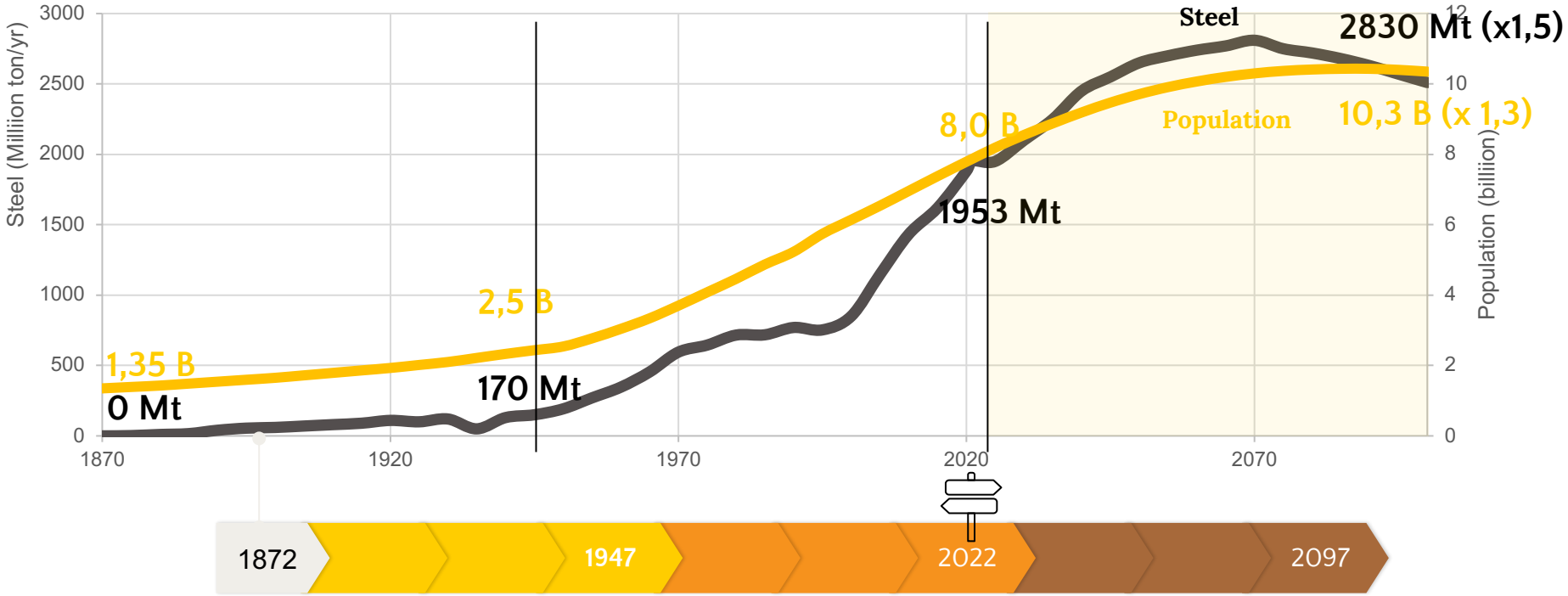
Steel is essential for the Energy Transition
One Example : Off-shore wind

EU plans 300 GW
off-shore wind in 2050

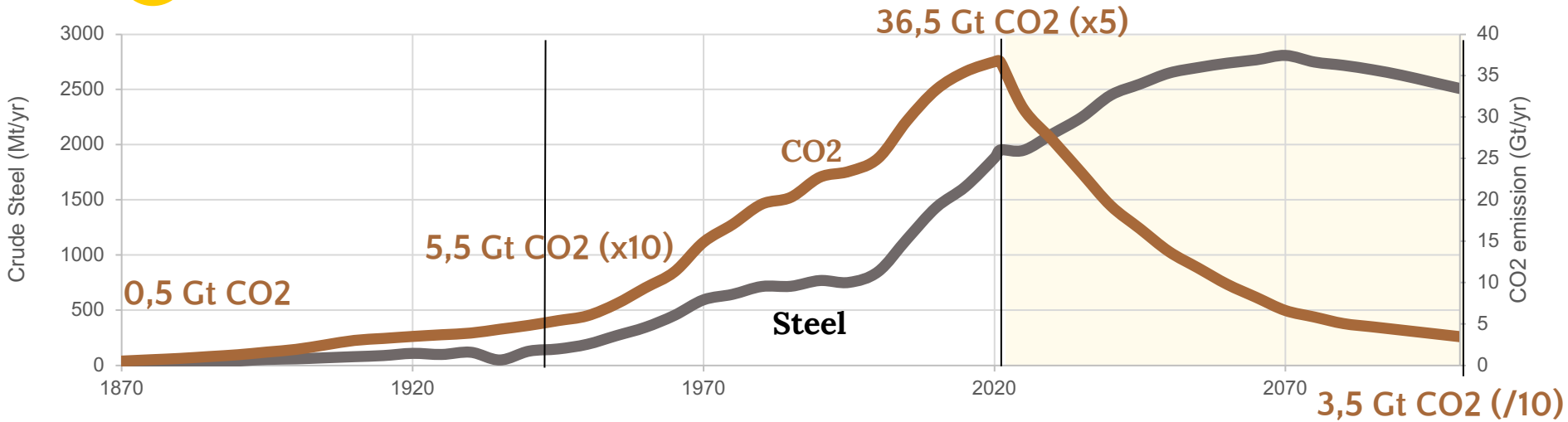
25.000 wind mills
HV lines, Transformers

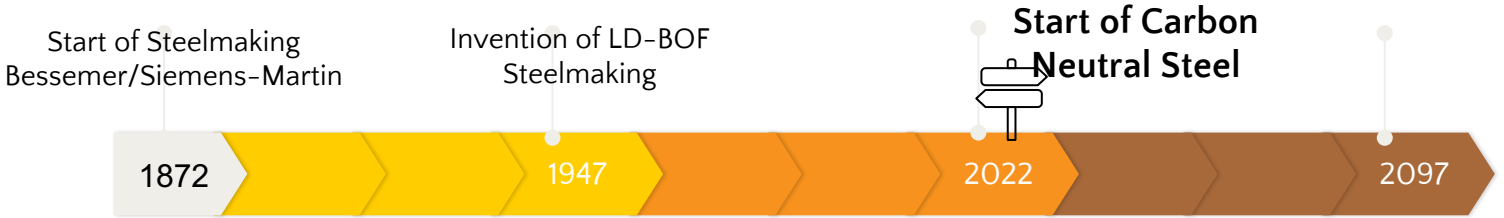
300 Mton steel
10Mt/yr

2022 – 2097 : 3th Cycle of 75 years

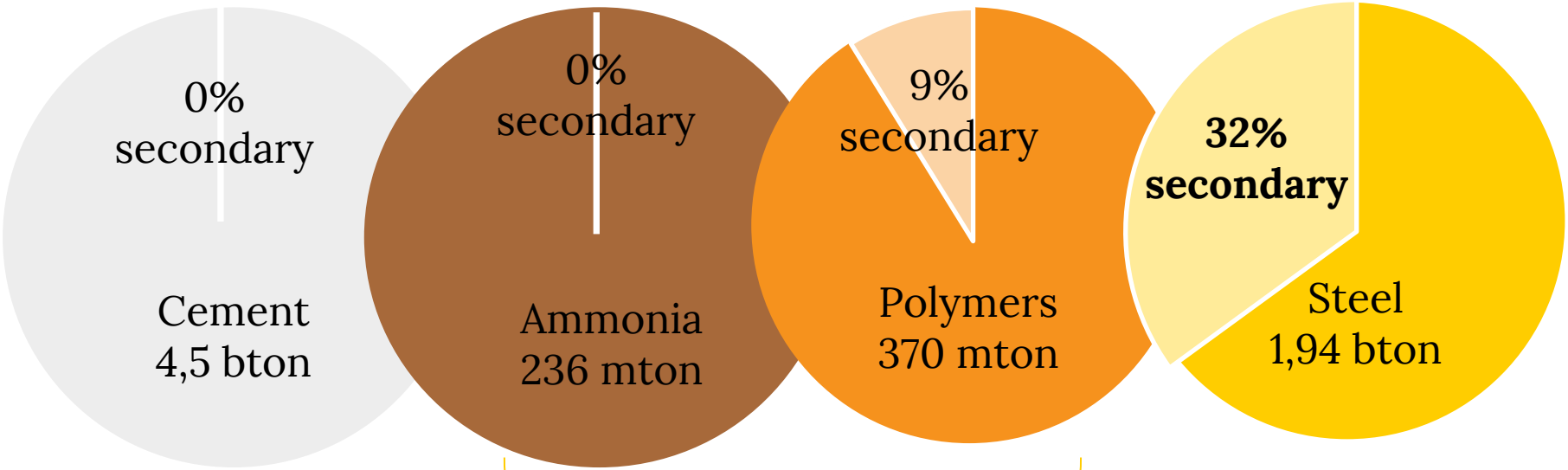


2022 – 2097 : The era of Smart Carbon Steelmaking





4 materials are essential and responsible for 25% of CO2 but *only steel is endless recyclable*



2,6 bton CO2 = 7%

3,0 bton CO2 = 8%

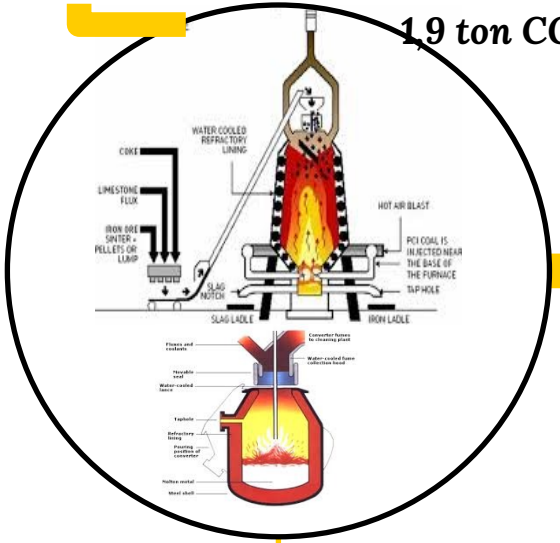
3,5 bton CO2 = 9%

Iron Ore

Primary Steel (68%)

2,35 ton CO2/ts (world)

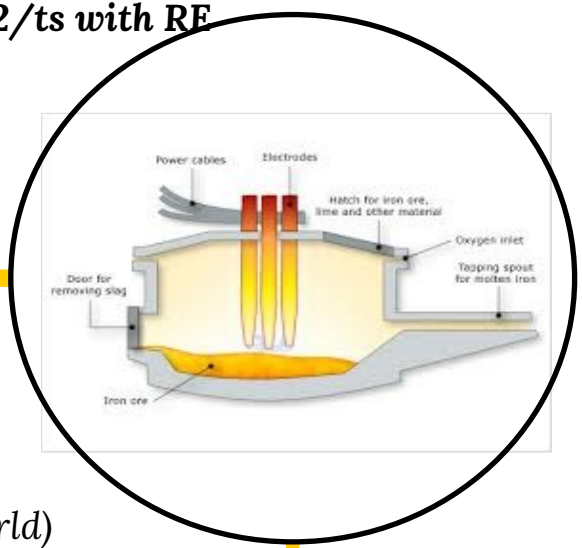
1,9 ton CO2/ts (EU)



Secondary Steel (32%)

0,6 ton/ ts CO2

0,2 ton CO2/ts with RE



Crude Steel

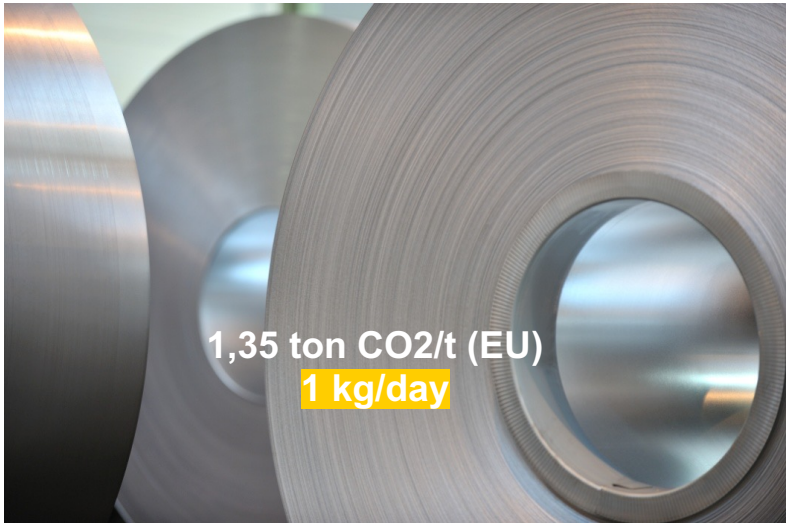
1,85 ton CO2/t (world)

1,35 ton CO2/t (EU)

Steel Scrap

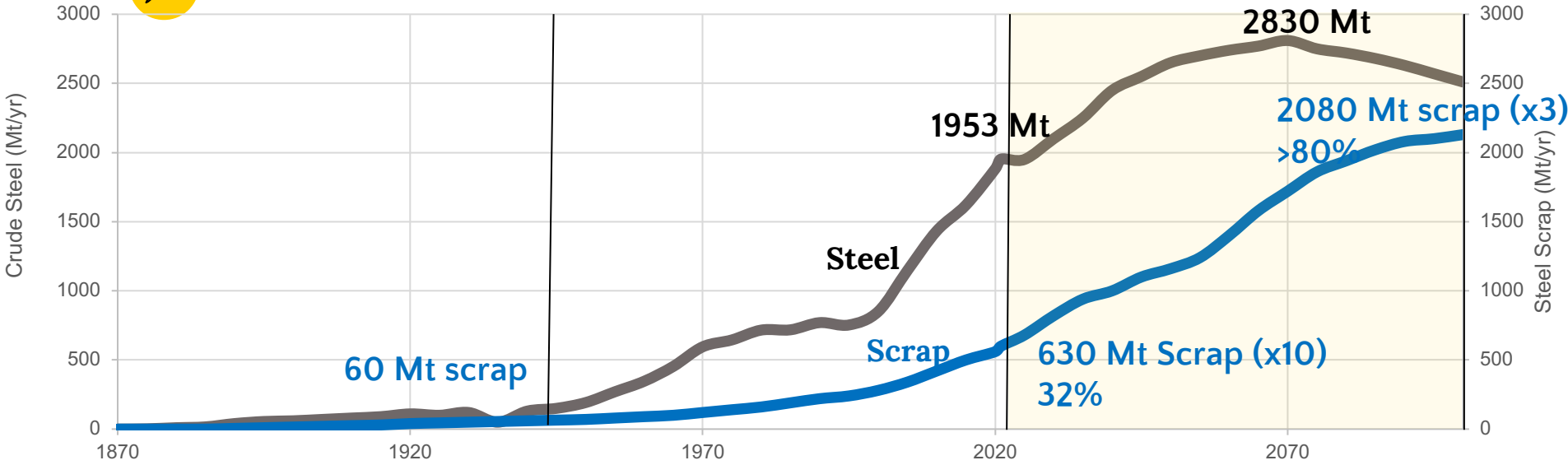
Steel Scrap

Steel footprint is comparable to Milk!



(*) if you are Dutch

The 3th Steel Cycle: growing steel demand balances with growing scrap arising until scrap recycling will be dominant



Need carbon neutral primary steelmaking for at least 60 years at current level of 1,3 bton

Hydrogen is starting to look like an economic bubble

Michael Liebreich,

At the 2022 World Hydrogen Summit in Rotterdam

Announcement of Top 5 Steel Producers to become Carbon Neutral in 2050

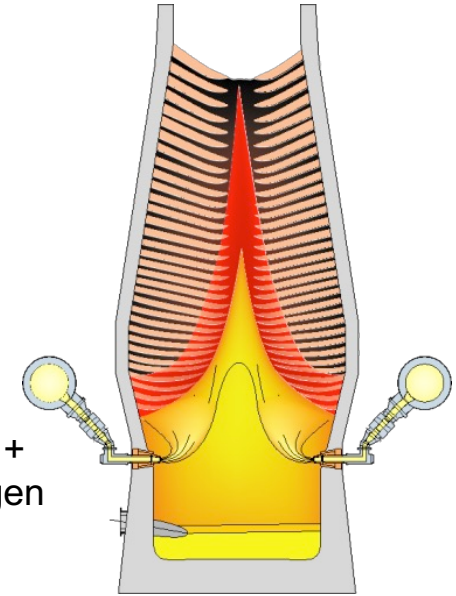
	Production in 2019 (mton)	Announcement
ArcelorMittal	97,31	September 2020
Baowu	95,47	January 2021
Nippon	51,68	December 2020
HBIS	46,56	March 2021
POSCO	43,12	December 2020

Announcement Top5 Steelmakers Carbon Neutrality
Source : own analysis

All EU Steelmakers announce to replace coal based Blast Furnace by Natural Gas based DRI technology

Iron ore → Iron
High Temperature Gas Reaction with CO and H2

Blast Furnace



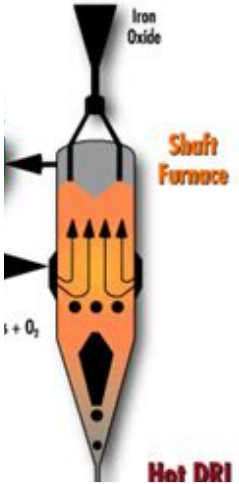
Coal + Oxygen

60% less direct emissions with natural gas
(scope 1 only)

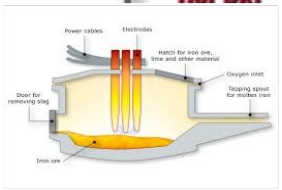
20% more energy consumption

Same total emissions with natural gas based power
(scope 1+ 2+ 3)

Direct Reduced Iron + EAF

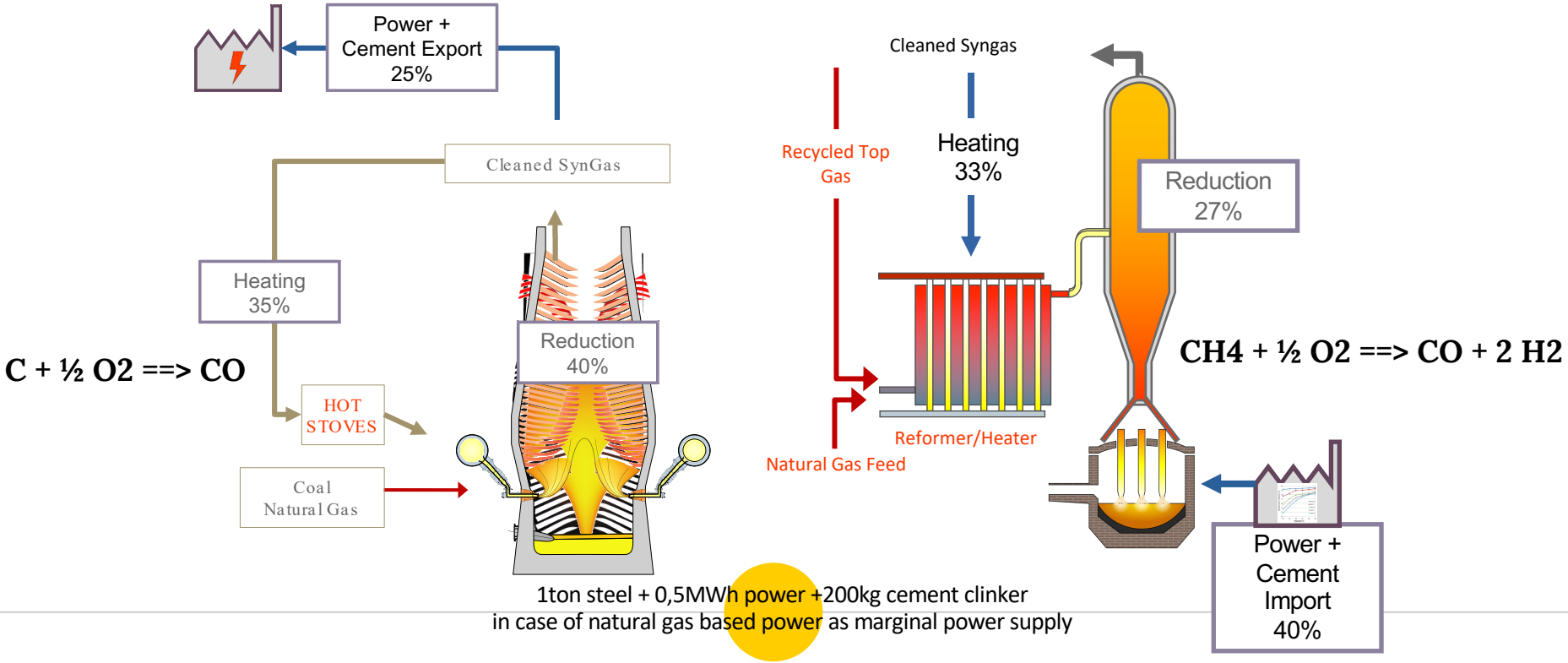


Natural Gas + Oxygen



Power

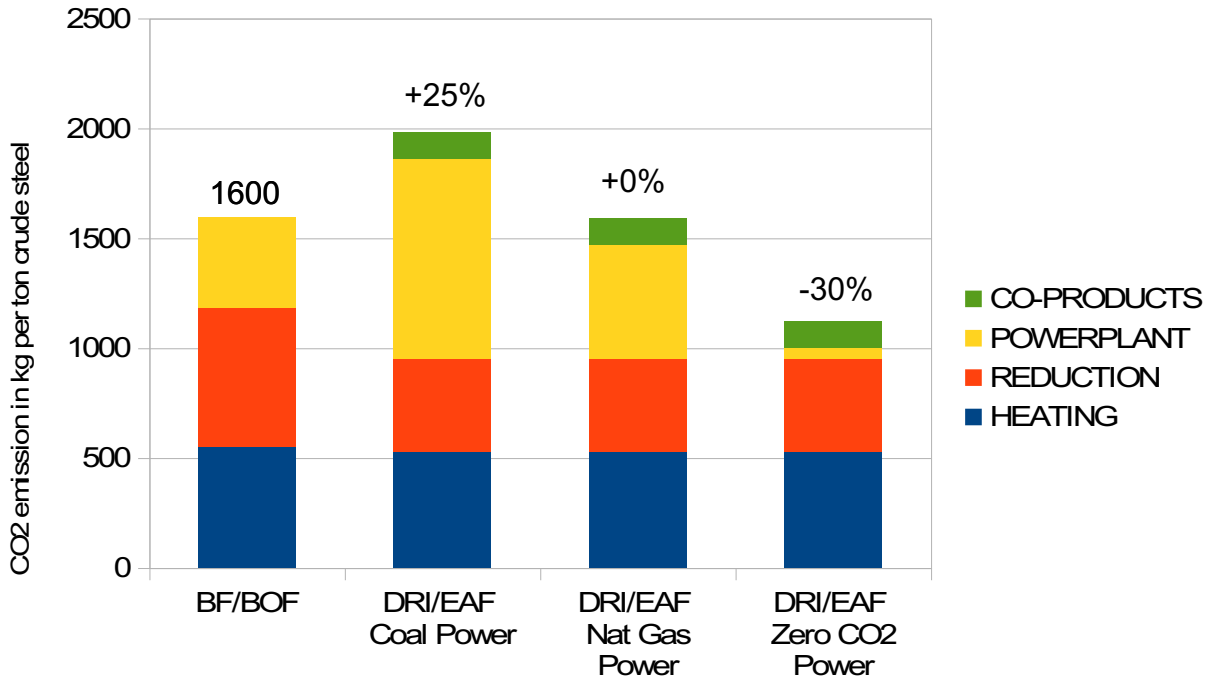
CO2 footprint assessment need to be done with the same system boundaries



1ton steel + 0,5MWh power +200kg cement clinker
in case of natural gas based power as marginal power supply

Generation of CO2 in BF/BOF plant and DRI/EAF plant with same boundary conditions
Source : own analysis

CO2 footprint per ton steel for BF/BOF and DRI /EAF with the same system boundaries



1ton steel + 0,5MWh power +200kg cement clinker
in case of natural gas based power as marginal power supply

Steel Footprint for BF/BOF and DRI/EAF for same system boundaries
Source : own analysis

The Hydrogen opportunity for Carbon Neutral Steelmaking

Reduction Function :

$$Fe_2O_3 + 6\,CO = 2\,Fe + 3\,CO + 3\,CO_2 + 26{,}6\ kJ \qquad (1)$$

$$Fe_2O_3 + 6\,H_2 = 2\,Fe + 3\,H_2 + 2\,H_2O - 99{,}5\ kJ \qquad (2)$$

Heating Function :

$$C + O_2 = CO_2 + 394\ kJ \qquad (3)$$

$$H_2 + O_2 = H_2O + 240\ kJ \qquad (4)$$

Substitution of C by H2 for Reduction and Heating
Source : own analysis

Industrial Experience with Hydrogen Ironmaking

The Circored plant in Point Lisas, Trinidad in 1999

CircoRed
Source : Dirk Nuber, Millenium Steel 2006

Eliminating Carbon by Hydrogen Steelmaking requires Electrolysis with CO2 free power

DRI fuel	Natural gas	Hydrogen from SMR based DRI	Hydrogen from SMR + CCS (89%)	Green Hydrogen with Renewable power
Fuel per ton DRI	10,5 GJ	84 kg	84 kg	84 kg
CO2 kg per unit fuel	59 kg	9,5 kg	1,05 kg	0 kg
CO2 kg per ton DRI	620 kg	798 kg	88 kg	0 kg
% vs Natural Gas		129,00%	15,00%	0,00%

CO2 footprint for DRI iron
Source : Dirk Nuber -Millenium Steel 2006, own analysis

For 1,38 billion ton of primary steel, we need...

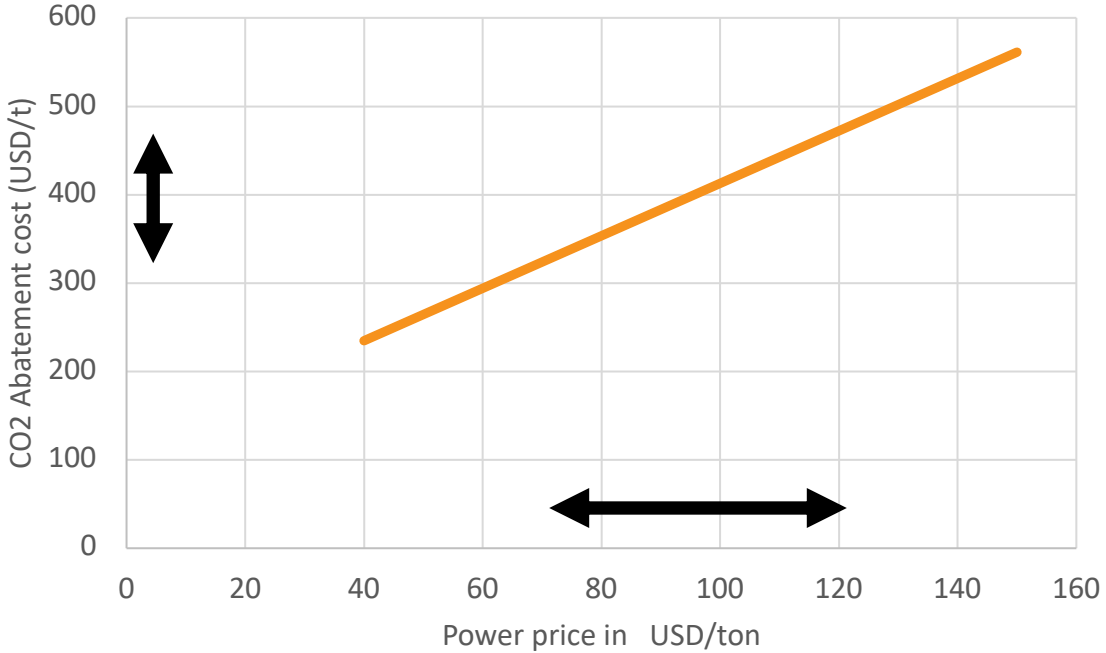
- 115,9 Mt Hydrogen = 123% current hydrogen
- 4,2MWh/t steel
- 5800 TWh
  = 176% of all RE world wide today
  = 20% of all sun+wind in 2050!

Hydrogen based Steelmaking?

800 nuclear reactors of 1000 MW (1)

(1) Number of Reactor world-wide today = 450

If all other costs remain equal, H2-DRI CO2 abatement cost is in the range of 350 to 500 USD/ton, but …



Source : IEA, 2021, Net Zero by 2050

… still there are other challenges before we can ban Carbon.

- Only 3 to 7% of the known iron ore sources are suited for DRI
- The productivity of the CO+H2 gas reduction process is rapidly dropping once the CO content is going to zero
- Melting point of carbon free iron is at 2000°C, not compatible with EAF
- CO formation in the current BOF process is essential to produce high quality steels
- …

The Hydrogen Swiss Army Knife

Credit concept : Paul Martin

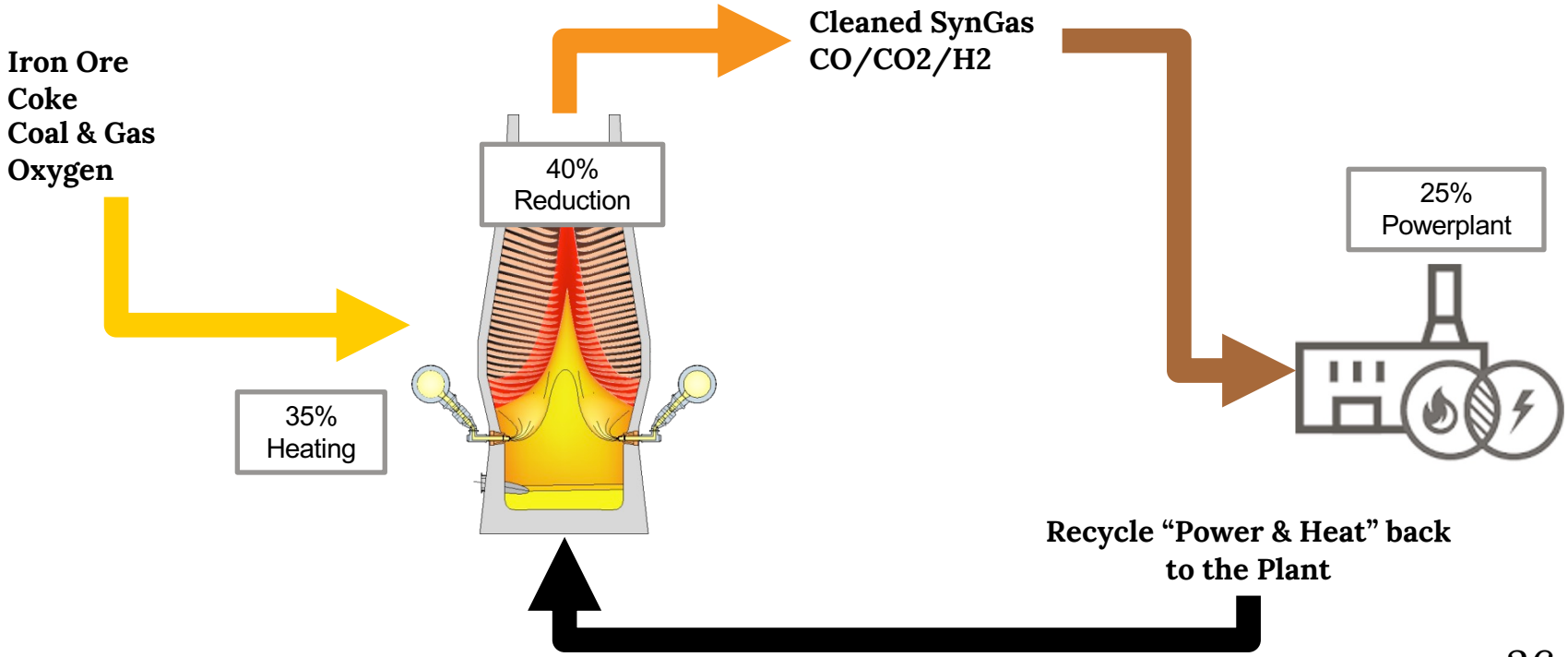
“In almost all use cases there is a good reason why hydrogen is not currently used - because other solutions are cheaper, simpler, safer or more convenient”, Michael Liebreich

Persistance is to the character of man as carbon is to steel

Napolean Hill, Amerian Author,
after interview with Andrew Carnegie in 1908

Paradigm Shift Required : From Current Lineair Carbon To ...

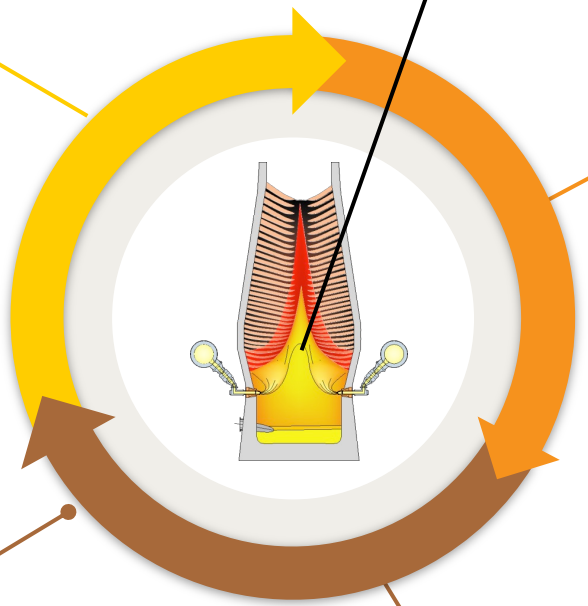
$FeO + C + O2 \rightarrow Fe + CO + CO2 + Heat$



.... A Circular Carbon Model
Be Smart, Imitate Nature !

1. Electrify the high temperature heat

5. Capture CO2 for export (CCS)

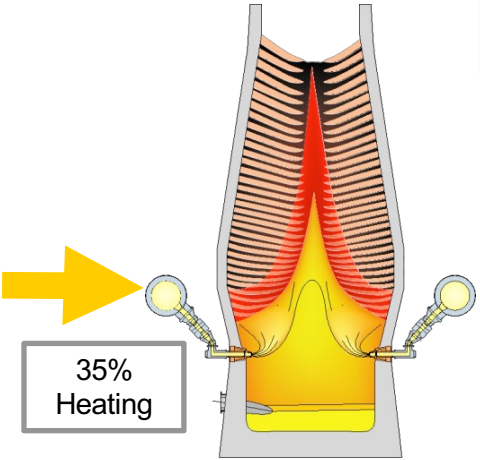


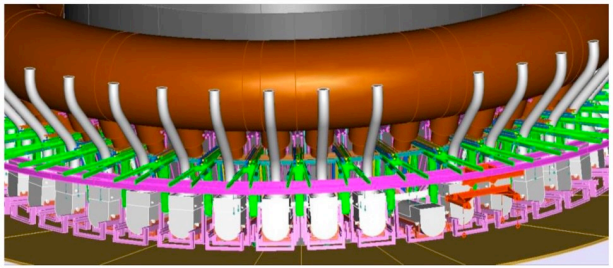
2. Re-use CO/CO2 and Green H2 to produce chemicals (CCU)

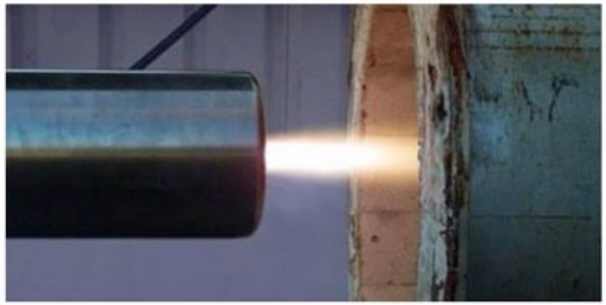
4. Inject H2 in existing BF/DRI based on its availability (H2)

3. Re-cycle waste streams as Circular Carbon

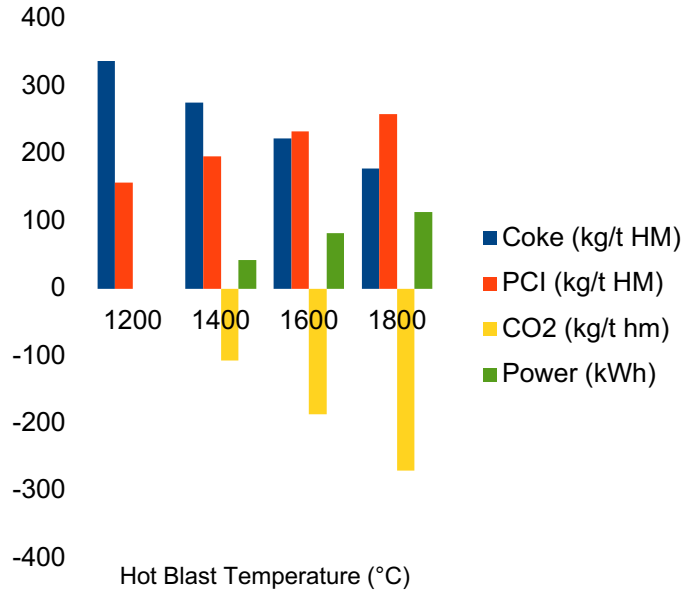
1. Electrification of High Heat by Plasma Torches







Replace Hot Blast
250kWh / ton
- 220 kg CO2 / ton

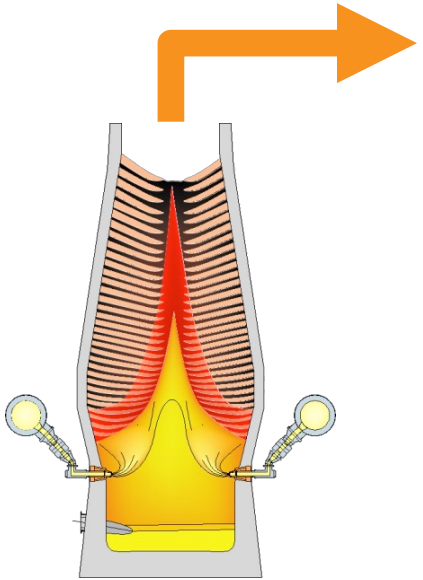


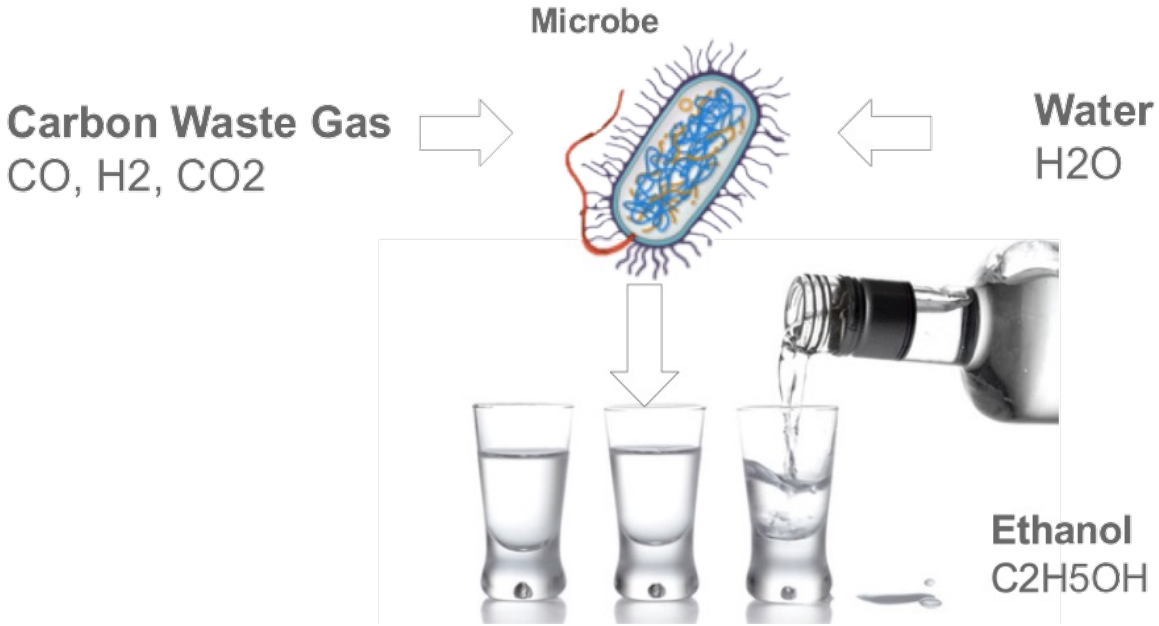
Superheat Hot Blast
120kWh / ton
- 270 kg CO2 / ton

Source : Ulcos research; ESTEP Workshop, Feb 2018; own analysis

2. CCU: Convert Syngas to Chemicals

Gasfermenation by Lanzatech

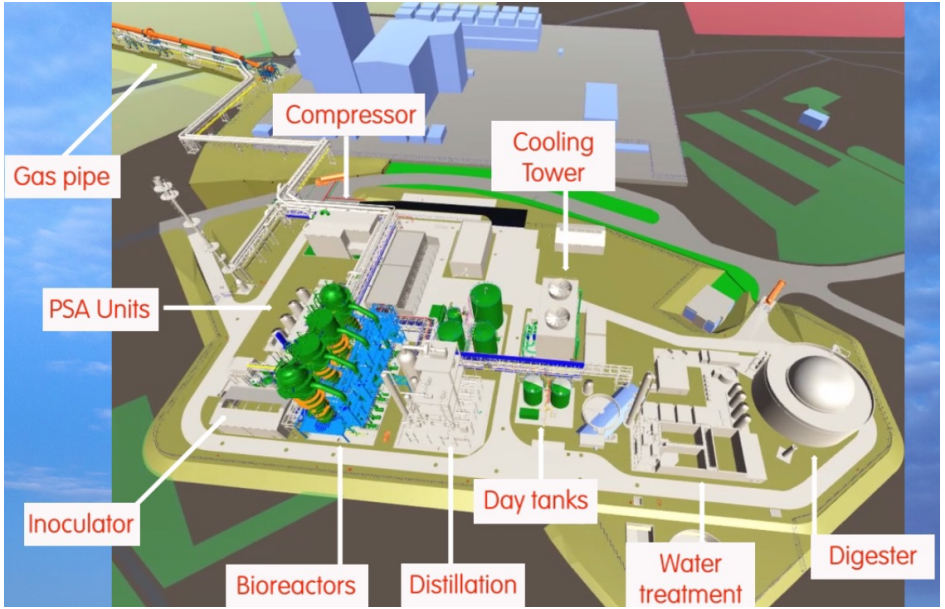




Source : Lanzatech, Steelanol website

2. CCU: Convert Syngas to Chemicals

First Gasfermentation plant in Europe at AM Belgium

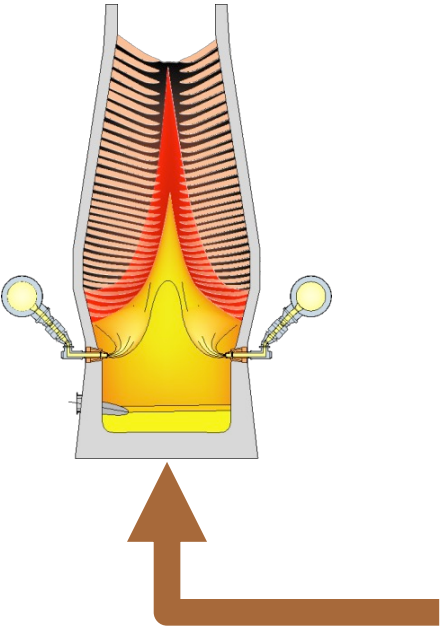


80 million liter Ethanol
200 mEUR investment

Source : Lanzatech, Steelanol website

3. Re-cycle Waste into Circular Carbon

Waste Wood at Torero plant of AM Gent



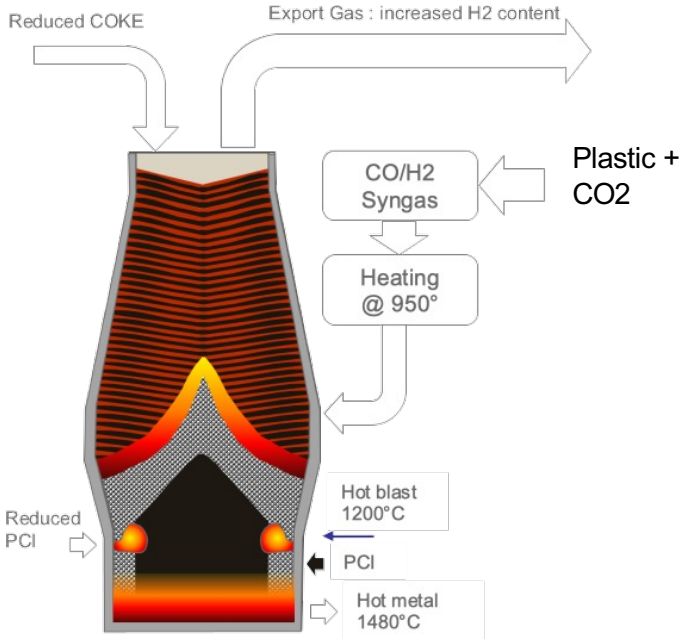
Replace 50kg/t Coal

= 10Mt waste wood

= 20% of collected amount

3. Re-cycle Waste into Circular Carbon

The Hidden Secret of the Blast Furnace (and reuse CO2 as oxygen source)



Monolith Materials in USA
16MWe Plasma Torch for Gasification and Reforming

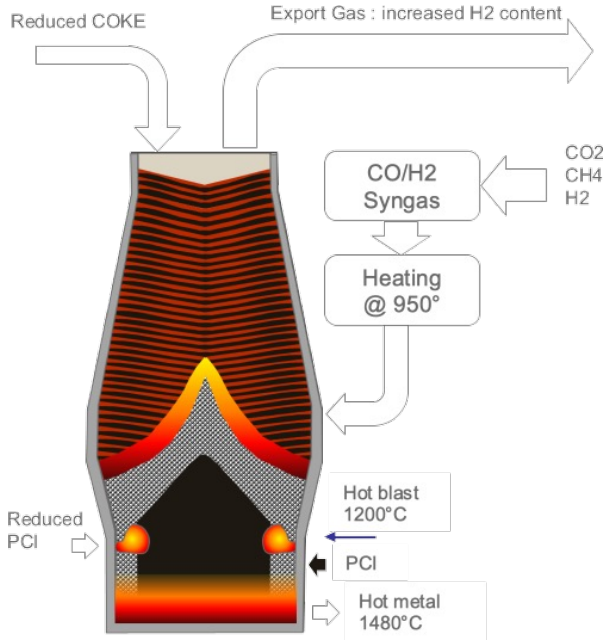
Replace 3 GJ of Nat Gas injected in BF

= 11Mt plastic waste

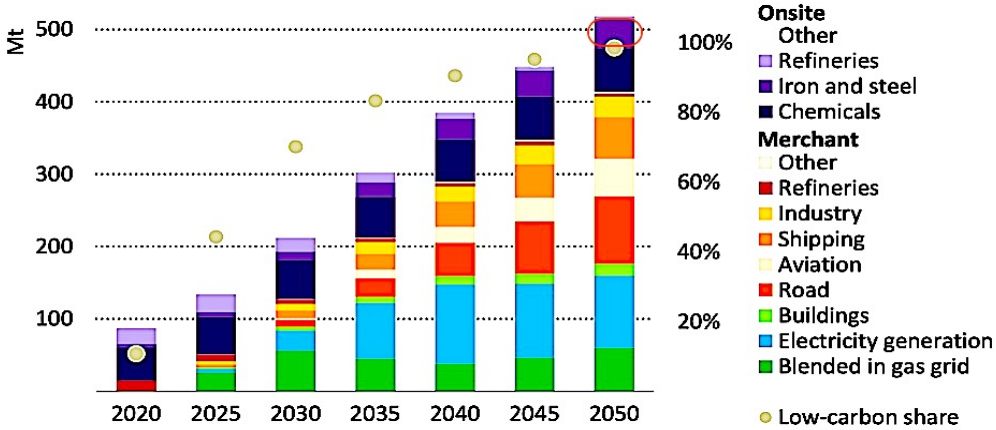
= 20% of collected amount

4. H2 injection in Existing BF and DRI

25kg/t H2 is possible today and will come available



IEA 2021 Net Zero By 2050 :
35Mt H2 supply for I&Steel results in 25kg/t



Source : Own analysis, IEA 2019 The Future of Hydogen, IEA 2021 Net Zero by 2050

5. Capture CO2 for Export (CCE)

Low cost CO2 capture to import renewable energy as a molecule

“3D” project at ArcelorMittal DK
amines scrubber for CO2 capture from BF gas

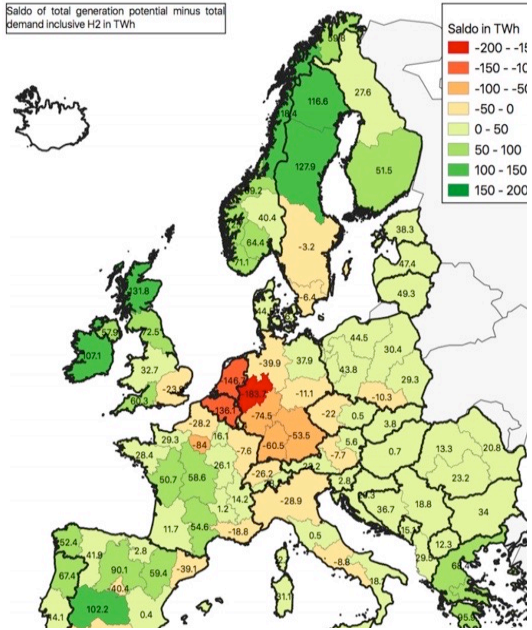
Scale : Upto 200kg CO2 / t steel with fatal waste heat

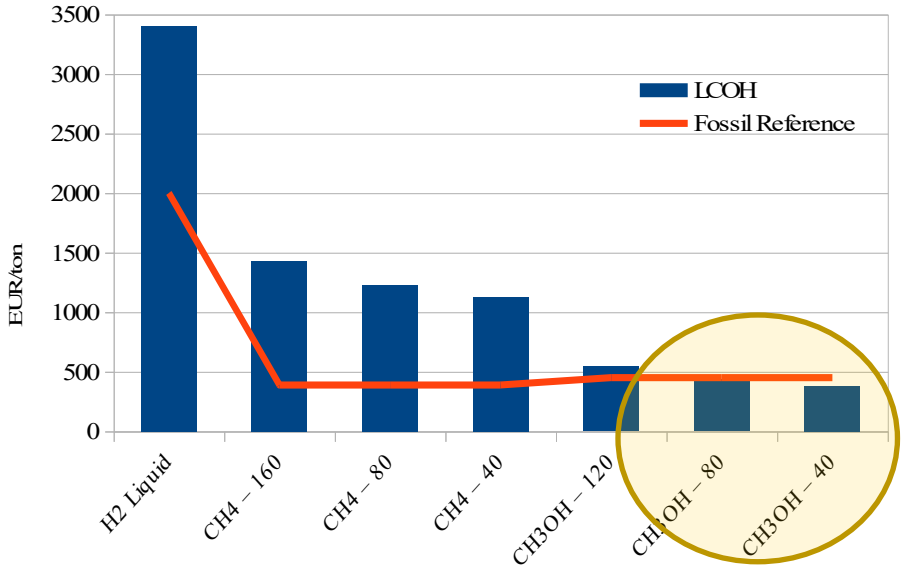
Opex : 40 to 80 EUR/t (ca min 25 EUR/t capture + 15EUR/t seaborn shipping)

Shipping CO2 – UK Cost Estimation Study. Final Report for BEIS
Source : 3D CCUS website; own analysis; elementenergy, nov 2018

5. Capture CO2 for Export (CCE)

Low cost CO2 capture to import renewable energy as Molecule

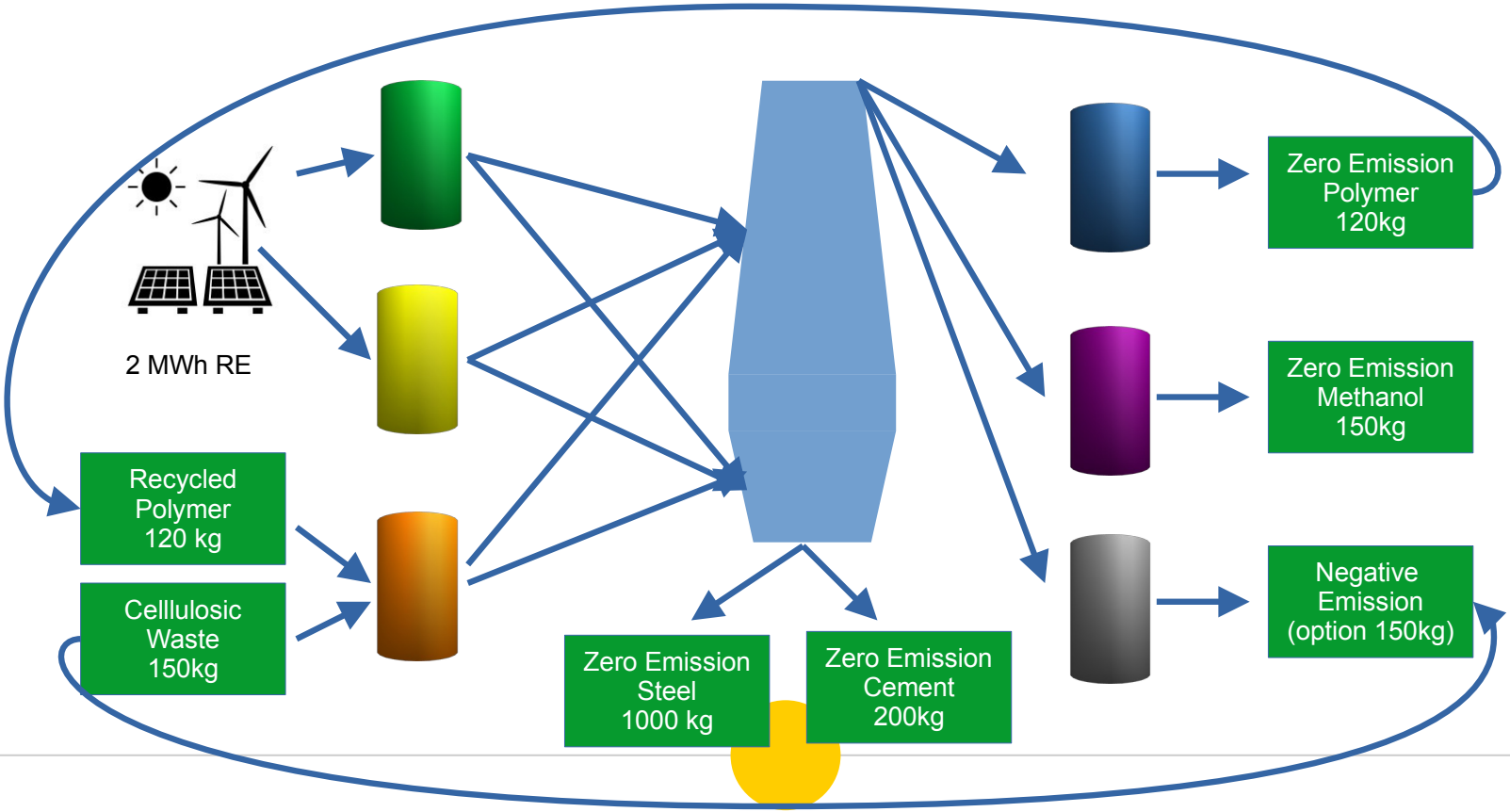




E-Methanol cost competitive if CO2 & 40 to 80 EUR/t

Source : Hydrogen Import Coalition Final Report, Januari 2021

Carbon Neutral Steelmaking : Circular



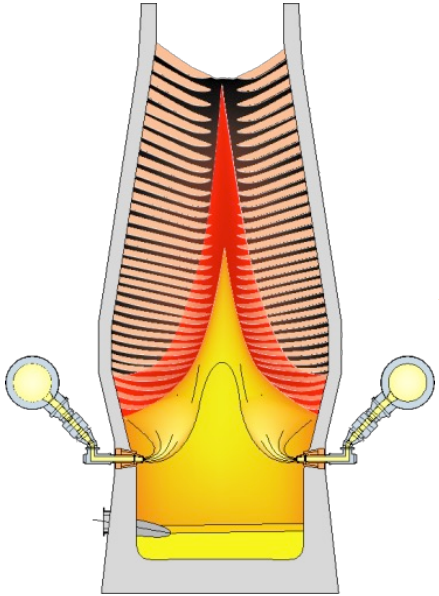
Carbon Neutral Steelmaking : Scalable

Today	BF/BOF 1600 kg/t	DRI/EAF 1100 kg/t	Resources Required
Hydrogen injection	-350 kg	-250 kg	25 kg H2 injection
Electrification HT Heat	-300 kg	-200 kg	1MWh
Torrefaction & Gasification	-350 kg	-250 kg	20% EU waste
CCU	-400 kg	-200 kg	Waste Gas to Chemicals to polymers
CCE/CCS	-200 kg	-200 kg	Export CO2 and Import RE as molecule
2050	0 kg	0 kg	Net-Zero

Source : own analysis

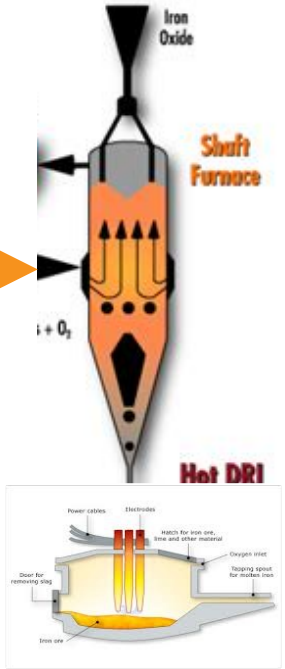
Energy Intensive Industry need New Narrative with focus on “Just-Transition” and Affordability

Two Conflicting narratives are paralyzing Climate Actions



CCS

Green H2



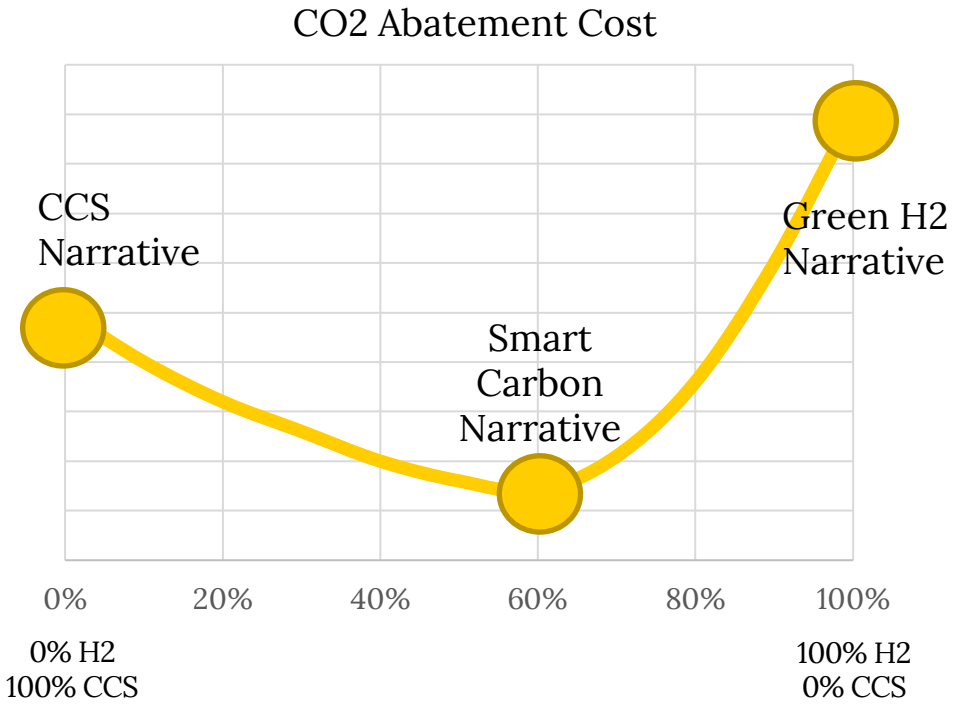
1. Deterministic Endgame
   Not Resiliance for “Black Swans”

2. ”Law of Diminishing Return”

Source : Int J. of Greenhouse Gas Control, December 2020

Energy Intensive Industry need New Narrative

Carbon Neutral Steelmaking : Affordable



Commercially available

Step-wise deployment on Existing Assets

Optimal Scale for each Technology

New Jobs and Value Thanks to Circular Economy

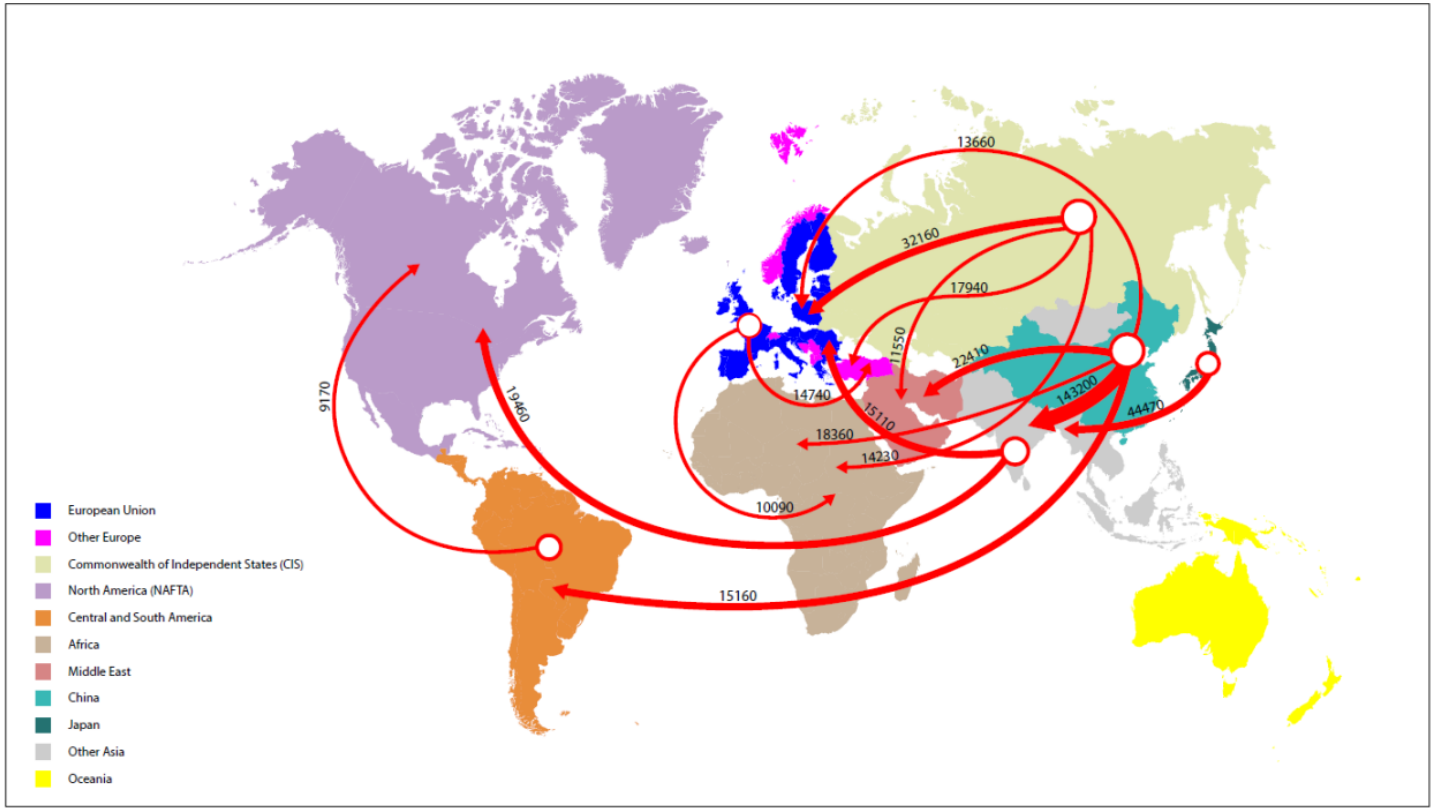
Whoever speaks of Europe is wrong:
it is a geographical expression

”Otto von Bismarck”, Minister President of Prussia 1862-1890

“

Strength of Europe: its Geography and the North Sea

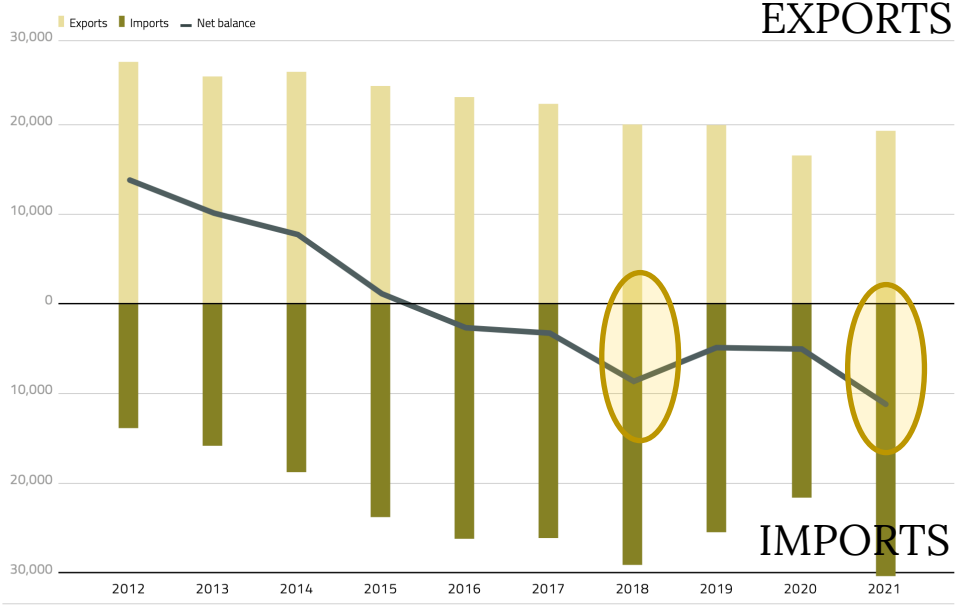
Steel and Steel Intensive Products are global



We need more creative Climate Policies to keep the EII in Europe

ETS CO2 prices evolution 10 years

EU steel industry decline last 10 years



Why Carbon will remain essential for the transition to Carbon Neutral Steelmaking

- Today we are at the start of new 75year Steel Era focusing on Carbon Neutrality
- Steel will continue to grow until 2080, but based on increased scrap arising. At the end of the century, CO2 emissions of steel will reduce with 60% thanks to scrap.
- Primary Steelmaking is required for the next 50 years at current production level and is the main CO2 emitting process step.
- Shifting to H2-Steelmaking is not expected to become mainstream (lack energy efficiency, key issues to ban carbon, high CO2 abatement cost)
- Smart Carbon Steelmaking combines 5 key technologies at the optimal cost, focusing on adding maximum value
- Steel will be at the center of the Circular Economy supporting a Just Transition by creating jobs and prosperity

Thanks!

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